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DETERMINISTIC SEISMIC HAZARD ANALYSIS OF A NEWLY CONSTRUCTED G+7 BUILDING AT WAH CANTT, PAKISTAN

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Abstract
This paper presents a site-specific Deterministic Seismic Hazard Analysis (DSHA) for a newly constructed G+7 building at Pakistan Ordnance Factories (POF), Wah Cantt. Seismogenic faults within approximately 150 km of the site were identified, maximum credible magnitudes were estimated from mapped fault lengths, and source-to-site distances were measured using Google Earth Pro. Peak Ground Acceleration (PGA) was computed using the Campbell (1981) and Boore and Atkinson (2008) ground motion prediction equations (GMPEs). The Main Boundary Thrust (MBT) was identified as the controlling source, producing the maximum PGA of 0.26 g. The adopted PGA was further converted into preliminary response-spectrum parameters of Ss = 1.05 g and S1 = 0.31 g. The findings need for structural verification of the existing G+7 building and support site-specific seismic assessment for future multi-storey development in the POF Wah Cantt.

1. Introduction
Seismic hazard analysis is an essential component of earthquake-resistant planning and structural design. Historically, seismic hazard evaluation developed through deterministic scenario-based approaches and later through probabilistic frameworks that account for recurrence, uncertainty, and exceedance probability. In broad terms, Deterministic Seismic Hazard Analysis (DSHA) evaluates a selected earthquake scenario, typically the maximum credible earthquake on a controlling source, whereas Probabilistic Seismic Hazard Analysis (PSHA) integrates the contribution of multiple sources, magnitudes, recurrence rates, and ground-motion variability over a selected return period (Cornell, 1968; Cornell et al., 1979; Reiter, 1990; Kramer, 1996). Other commonly used seismic hazard procedures include PSHA, deterministic scenario analysis, seismic microzonation, site-response analysis, and code-based seismic zoning. Each approach has a different purpose. PSHA is useful for regional hazard maps and risk-informed design levels; microzonation and site-response studies refine the influence of local soil and basin conditions; and DSHA is particularly useful where a specific site, structure, or critical facility must be checked against a credible controlling earthquake scenario. Pakistan Ordnance Factories (POF), Wah Cantt, is a strategically important industrial and residential area in northern Punjab, Pakistan. It

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includes critical defense manufacturing facilities and accommodation for military personnel, employees, and families. The traditional built environment of Wah Cantt has mainly consisted of low-rise construction. However, increasing population pressure, limited land availability, and growing infrastructure demand have encouraged multi-storey construction, including the newly constructed G+7 building considered in this study.

The shift from low-rise to multi-storey development improves land use but increases the importance of reliable seismic input for structural verification. Wah Cantt lies within the Potwar Plateau, close to the Himalayan fold-and-thrust belt, where active regional and local faults can generate moderate to strong ground shaking. Because regional code maps may not fully capture the influence of nearby seismogenic sources at a particular site, a site-specific DSHA is appropriate for the POF G+7 building.

2. Regional Tectonic Setting and Study Area

Pakistan is located at the junction of the Indian, Eurasian, and Arabian plates. The northward movement of the Indian Plate against the Eurasian Plate has formed the Himalayan mountain belt and several active tectonic structures relevant to northern Pakistan, including the Main Boundary Thrust (MBT), Main Mantle Thrust (MMT), Himalayan Frontal Thrust, Salt Range Thrust, and local Potwar Plateau fault systems (MonaLisa, 2009; Sultan, 2015).

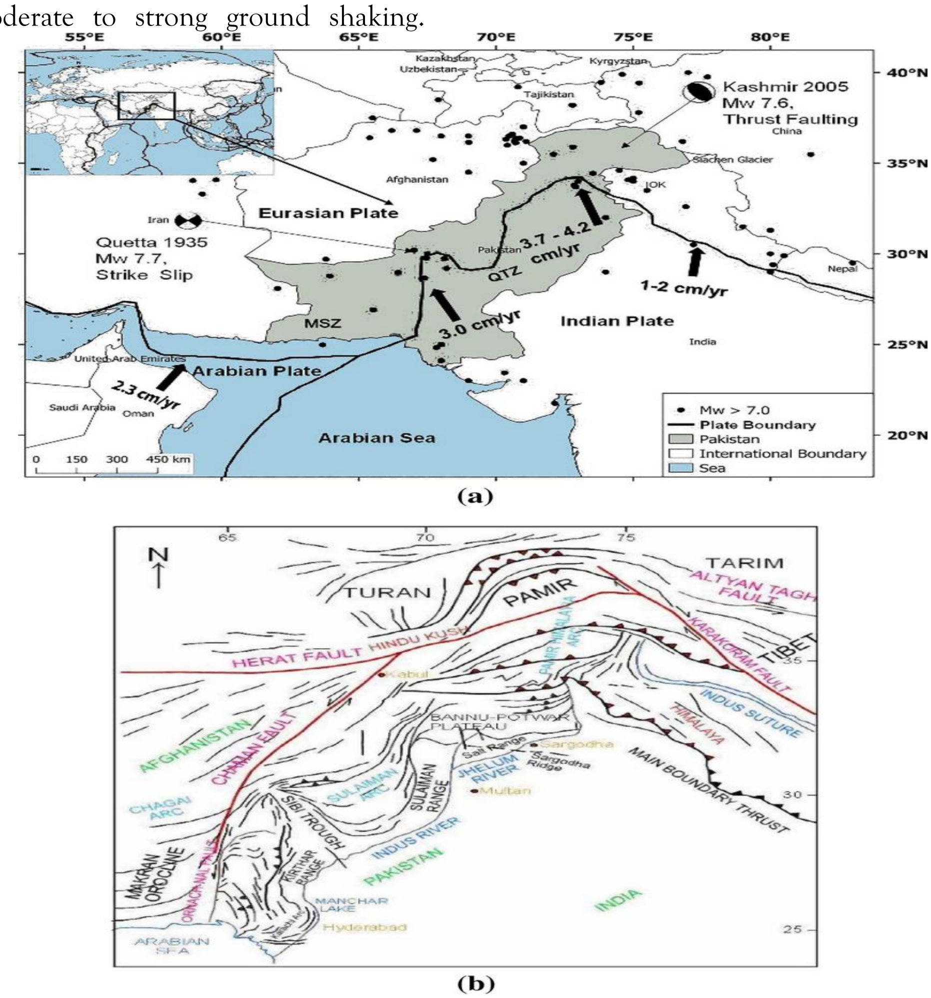

*Figure 1. **Tectonic setting of Pakistan showing the interaction of the Indian, Eurasian, and Arabian plates and major regional fault systems.** Source: adapted from regional tectonic maps reported by MonaLisa (2009) and Sultan (2015).*

The fault-line map of Pakistan indicates dense fault systems in the northern and western regions. For Wah Cantt, the most relevant sources are the Himalayan frontal structures and the local Potwar Plateau thrust systems, which may control the possible seismic input at the site.

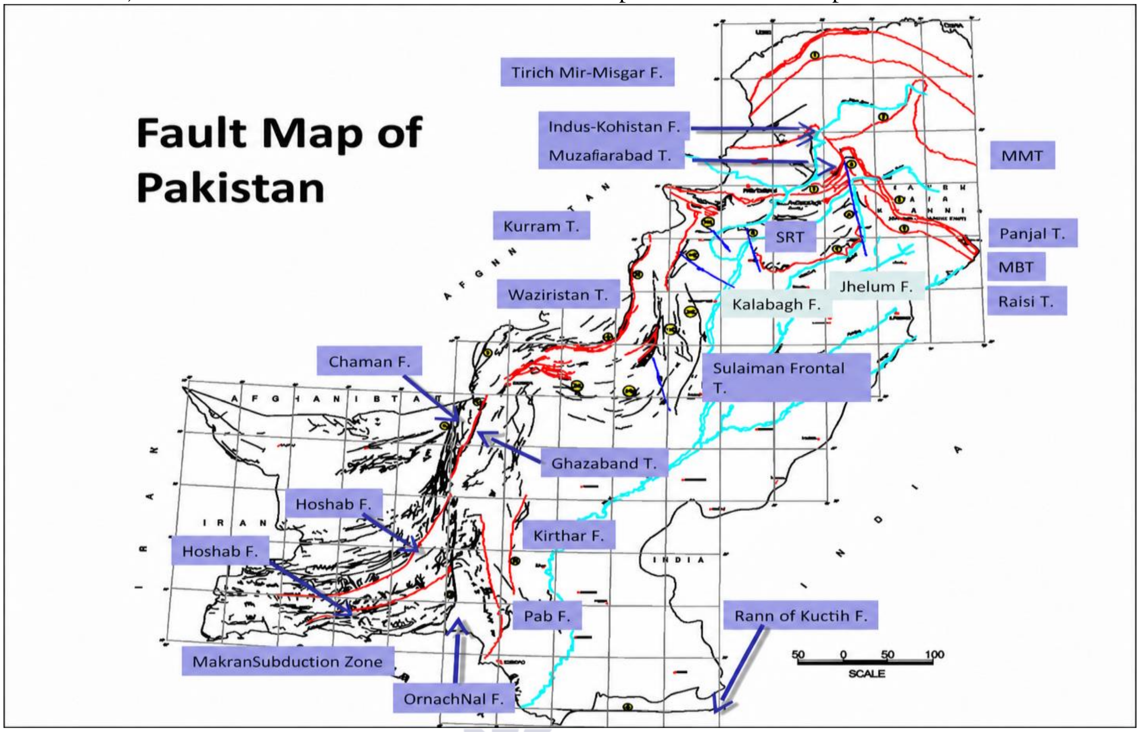

Figure 2. Major active fault lines of Pakistan. *Source: adapted from the Pakistan fault-line map/NESPAK (2006), as reproduced in regional seismic-hazard literature.*

The study area is Pakistan Ordnance Factories, Wah Cantt, located in northern Punjab, Pakistan. The reference site is the newly constructed G+7 building within the POF area. A radius of approximately 150 km around the building was adopted to identify seismogenic faults capable of contributing significant ground motion at the site.

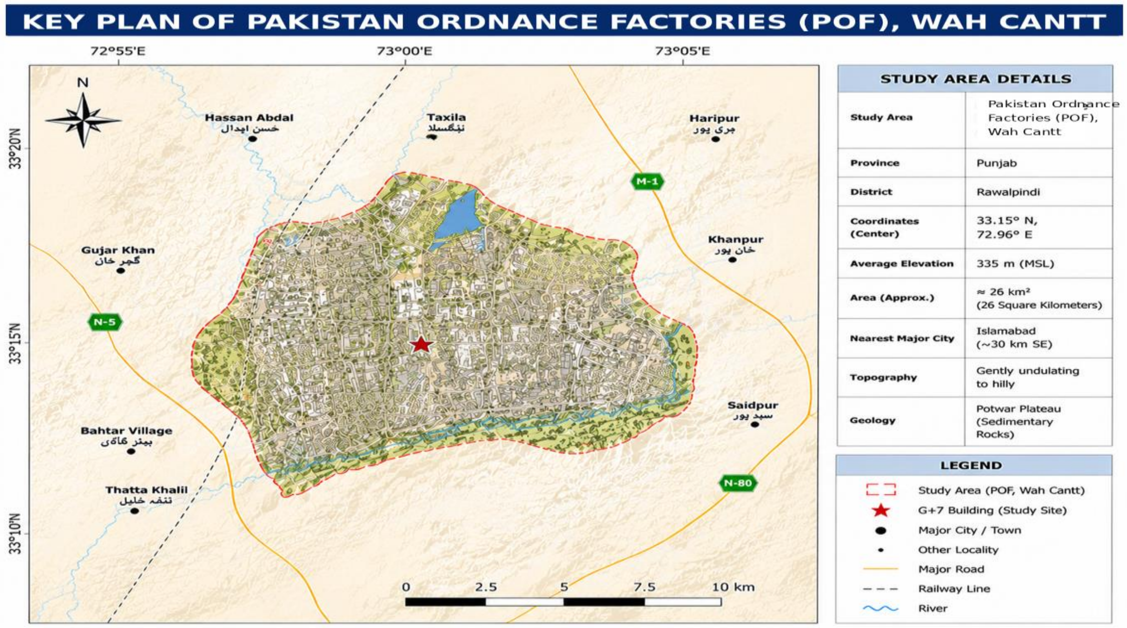

Figure 3. Key plan showing the location of Pakistan Ordnance Factories, Wah Cantt, and the G+7 building study site.

Figure 4. Aerial view of the newly constructed G+7 building site at POF Wah Cantt.

Figure 5. Newly constructed G+7 building at POF Wah Cantt

3. Research Problem and Objectives

3.1 Research Problem

POF Wah Cantt is moving toward G+7 multi-storey construction, but the site-specific seismic demand for the newly constructed building has not been verified through DSHA. Therefore, a deterministic evaluation is required to identify the controlling seismogenic source, estimate the governing PGA at the site, and compare the result with the Building Code of Pakistan 2021.

3.2 Objectives of the Study

- To perform site-specific DSHA for the newly constructed G+7 building by identifying relevant seismogenic faults within an approximately 150 km radius and estimating the controlling PGA.
- To compare the DSHA-derived PGA with the Building Code of Pakistan 2021 value and develop preliminary site-specific seismic input parameters for structural verification.

4. Methodology

4.1 Deterministic Seismic Hazard Analysis

The adopted procedure included the following steps:

- Identify active or potentially active seismic sources within the selected study radius.
- Estimate the maximum credible magnitude for each source using mapped fault length and empirical magnitude-scaling relationships.
- Measure the shortest source-to-site distance for each fault.

- Calculate PGA for each source using selected GMPEs.
- Select the controlling earthquake as the source producing the maximum PGA at the site.
- Compare DSHA-derived PGA with the Building Code of Pakistan 2021 design PGA range for Wah Cantt.

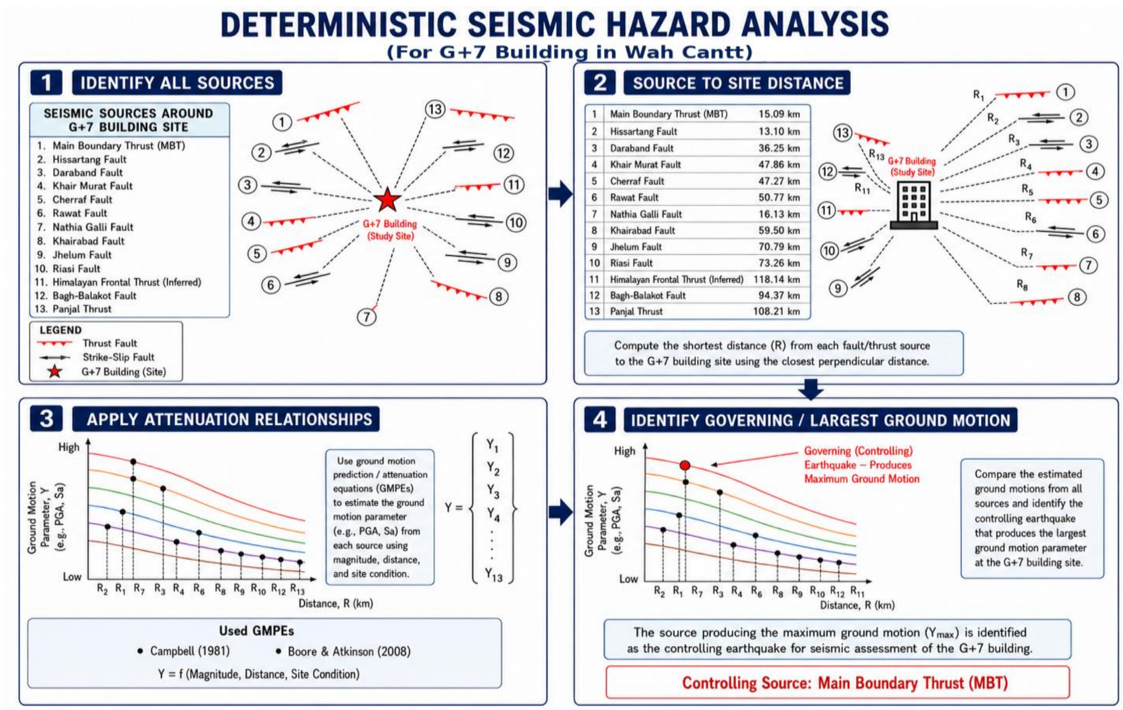

Figure 6. Deterministic hazard analysis workflow used for source identification, distance measurement, attenuation modeling, and controlling ground-motion selection.

4.2 Identification of Seismic Sources

Seismic sources were selected from regional tectonic maps, fault-line maps, earthquake epicenter distribution, and mapped fault traces around Wah Cantt. Faults within approximately 150 km of the study site were considered because sources with sufficient rupture length and magnitude potential can contribute meaningful deterministic ground motion even when located at moderate distances.

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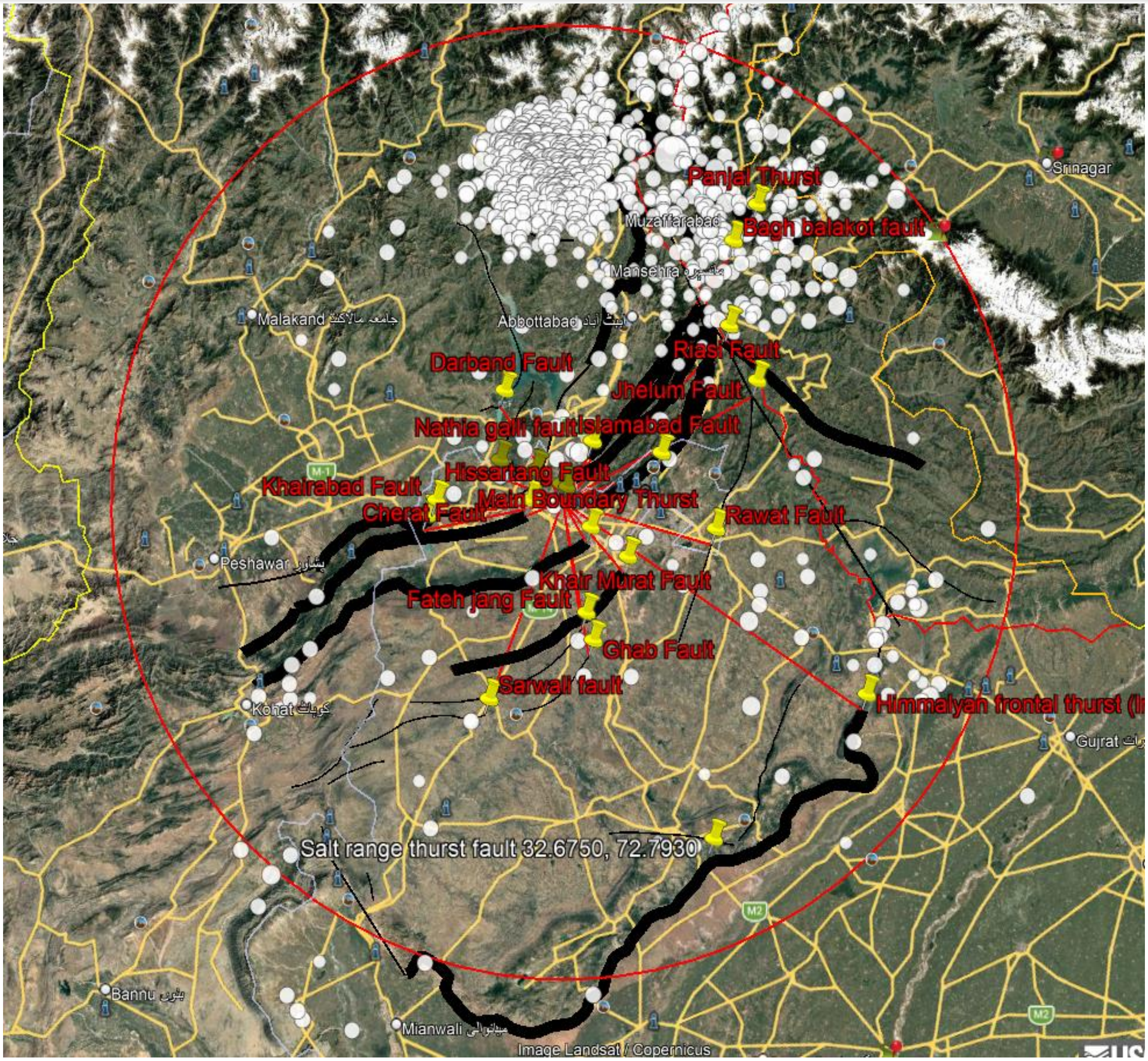

Figure 7. Earthquake epicenters and mapped fault traces within approximately 150 km of the G+7 building site in Wah Cantt.

4.3 Magnitude and Distance Parameters

Maximum credible magnitudes were estimated from mapped fault lengths using empirical magnitude-scaling relationships. Source-to-site distances were measured using Google Earth Pro and were tabulated for each candidate source. The fault length, distance, and magnitude values used in this study are summarized in Table 1.

Table 1. Fault lengths, coordinates, source-to-site distances, and estimated maximum credible magnitudes.

No.	Fault Name	Decimal Coordinates	Length (km)	Distance to Site (km)	Mw
1	Main Boundary Thrust (MBT)	33.625731, 72.792453	381.00	15.09	8.0

No.	Fault Name	Decimal Coordinates	Length (km)	Distance to Site (km)	Mw
2	Hissartang Fault	33.764459, 72.627854	169.00	13.10	7.6
3	Daraband Fault	34.079602, 72.685138	47.00	36.25	7.1
4	Khair Murat Fault	33.506428, 72.876207	116.00	47.86	7.4
5	Cherat Fault	33.842137, 72.268311	40.00	47.27	6.9
6	Rawat Fault	33.478493, 73.200464	80.79	50.77	7.3
7	Nathia Galli Fault	33.847104, 72.909769	59.00	16.13	7.4
8	Khairabad Fault	33.870167, 72.317929	225.00	59.50	7.8
9	Jhelum Fault	33.816456, 73.530819	50.49	70.79	7.1
10	Riasi Fault	33.990336, 73.511899	200.00	73.26	8.0
11	Himalayan Frontal Thrust (Inferred)	32.876081, 73.476718	319.58	118.14	8.0
12	Bagh-Balakot Fault	34.206894, 73.638769	44.00	94.37	6.9
13	Panjal Thrust	34.273705, 73.765674	195.00	108.21	7.7

Table 2 summarizes the engineering relevance of the principal seismogenic faults considered for the POF Wah Cantt site. The Main Boundary Thrust is treated as the controlling regional source because it combines large magnitude potential with a short source-to-site distance.

Table 2. Description and relevance of principal seismogenic faults.

Fault	Engineering relevance to the study area
Main Boundary Thrust (MBT)	Regional thrust separating the Sub-Himalayas from the Lesser Himalayas; selected as the controlling source because it combines high magnitude potential with short source-to-site distance.
Hissartang Fault	Part of the Khairabad-Hissartang-Cherat thrust system near Attock and associated with the Himalayan fold-and-thrust belt.
Daraband Fault	One of the closest mapped sources to the site; located to the north within the northwestern Himalayan tectonic belt.
Khair Murat Fault	Active thrust-related structure near Taxila and the Khair Murat range within the Potwar Plateau.
Cherat Fault	Local thrust feature forming part of the Khairabad-Hissartang-Cherat fault system.
Rawat Fault	Southward-verging thrust fault near Rawat/Islamabad and an important local source in the Potwar Plateau.

Fault	Engineering relevance to the study area
Nathia Galli Fault	Local thrust feature in the Hazara region; included due to its proximity and estimated magnitude potential.
Khairabad Fault	Major thrust fault near the Indus-Kabul confluence; included because of its length and regional significance.
Jhelum Fault	Strike-slip fault forming the eastern boundary of the Potwar Plateau and related to regional seismicity.
Riasi Fault	Active Himalayan frontal thrust fault capable of generating large earthquakes.
Himalayan Frontal Thrust (Inferred)	Major frontal thrust system along the southern margin of the Himalayan fold-and-thrust belt; included due to its long rupture length, high magnitude potential, and broad influence on northern Pakistan.
Bagh-Balakot Fault	Active fault zone associated with the Hazara-Kashmir region; included because of its seismic significance and relationship with damaging earthquakes in northern Pakistan.
Panjal Thrust	Regional thrust fault related to the Himalayan tectonic system; included due to its considerable length, large earthquake potential, and influence on the regional hazard around Wah Cantt.

4.4 Ground Motion Prediction Equations
PGA was estimated using two documented GMPEs: Campbell (1981) and Boore and Atkinson (2008). These models relate earthquake magnitude, distance, fault mechanism, and site condition to expected ground motion. The use of two GMPEs provides a comparative basis for identifying the controlling source and adopting a conservative site-specific PGA for preliminary evaluation.

4.4.1 Campbell (1981) GMPE
The Campbell (1981) near-source attenuation relationship, as adopted in the referenced site-specific DSHA study, is written as:

$$\ln PGA(g) = -3.512 + 0.904 - 1.328\sqrt{(R^2 + [0.149 \exp(0.647M_w)]^2)} \quad (1)$$
$$+ (1.125 - 0.112 \ln R - 0.0957M_w)F + (0.440 - 0.171 \ln R)S_{SR}$$
$$+ (0.405 - 0.222 \ln R)S_{HR}$$

where PGA is peak ground acceleration in units of g, M is the earthquake magnitude, R is the epicentral/source-to-site distance in kilometres, F is 0 for strike-slip and normal faulting and 1 for reverse, oblique and thrust faulting, S_{SR} = 1 for soft rock, S_{HR} = 1 for hard rock, and S_{SR} = S_{HR} = 0 for alluvium sites.

4.4.2 Boore and Atkinson (2008) GMPE
The Boore and Atkinson (2008) attenuation relationship used for PGA prediction is written as:

$$\ln(PGA) = -1.715 + 0.5M - 1.0 \ln(R + 0.0055e^{(0.4M)}) + 0.3 \ln(VS30/760) \quad (2)$$

where M is the earthquake magnitude, R is the epicentral/source-to-site distance in kilometres, and VS30 is the average shear-wave velocity/site velocity in the upper 30 m in m/s. For this preliminary study, reverse/thrust faulting and representative stiff-soil conditions were considered where required; detailed geotechnical data should be used to refine the final design spectrum.

5. Results and Discussion
Table 3 presents the PGA values obtained from the selected GMPEs. The Main Boundary Thrust produces the highest PGA among the considered seismic sources, with a maximum tabulated value of 0.26 g from Boore and Atkinson (2008). This value is adopted as the site-specific seismic demand for structural verification of the G+7 building and as the DSHA-recommended design PGA for future multi-storey construction in POF Wah Cantt.

Table 3. Corrected PGA values for each seismic source.

No.	Fault Name	Mw	R (km)	Campbell (1981) PGA (g)	Boore & Atkinson (2008) PGA (g)
1	Main Boundary Thrust (MBT)	8.0	15.09	0.22	0.26
2	Hissartang Fault	7.6	13.10	0.16	0.18
3	Daraband Fault	7.1	36.25	0.15	0.14
4	Khair Murat Fault	7.4	47.86	0.13	0.14
5	Cherat Fault	6.9	47.27	0.09	0.10
6	Rawat Fault	7.3	50.77	0.11	0.12
7	Nathia Galli Fault	7.4	16.13	0.10	0.11
8	Khairabad Fault	7.8	59.50	0.13	0.14
9	Jhelum Fault	7.1	70.79	0.06	0.08
10	Riasi Fault	8.0	73.26	0.11	0.12
11	Himalayan Frontal Thrust	8.0	118.14	0.06	0.07
12	Bagh-Balakot Fault	6.9	94.37	0.03	0.05
13	Panjal Thrust	7.7	108.21	0.05	0.06

The results show that the controlling hazard depends on both magnitude potential and distance. Although the Hissartang Fault is the closest source, the Main Boundary Thrust controls the deterministic hazard because it combines high magnitude potential with significant influence at Wah Cantt.

5.1 Conversion of Adopted PGA to Spectral Acceleration Parameters

For response-spectrum-based structural evaluation, the peak ground acceleration obtained from the deterministic seismic hazard analysis was converted into short-period and one-second spectral acceleration parameters. In the present study, the controlling seismic source was identified as the Main Boundary Thrust (MBT), which produced the maximum deterministic PGA of 0.26 g. Therefore, the adopted site-specific deterministic ground-motion parameter is:

PGA_DSHA = 0.26 g

PGA alone is not sufficient for response-spectrum-based structural verification because the seismic demand of a building depends on the spectral acceleration at its fundamental vibration periods. Hence, the adopted PGA was converted into Ss and S1, where Ss represents the short-period spectral acceleration and S1 represents the spectral acceleration at one second. The conversion was not performed by directly assuming the seismic coefficient equal to PGA. Instead, a two-stage conversion and calibration approach was used so that the final spectral values are supported both by a published PGA-to-spectral conversion method and by the regional spectral shape of the Building Code of Pakistan 2021.

Stage 1: Empirical PGA-to-Spectral Conversion

As a preliminary conversion basis, the empirical relationships proposed by Lubkowski and Aluisi (2012) were used. Their study, "Deriving Ss and S1 Parameters from PGA Maps," developed relationships between PGA and spectral acceleration parameters using a database of more than fifty probabilistic seismic hazard studies from low, moderate and high seismicity regions. The study notes that the traditional Ss/PGA ratio is often taken approximately as 2.5, but the ratio varies with PGA level and regional seismicity. Therefore, their regression-based equations provide a rational basis for estimating Ss and S1 from PGA when only PGA is available at the site.

The relationships used are:

Ss / PGA = 0.3386(PGA) + 2.1696

S1 / PGA = 0.5776(PGA) + 0.5967

Substituting PGA_DSHA = 0.26 g:

Ss / PGA = 0.3386(0.26) + 2.1696 = 0.0880 + 2.1696 = 2.2576

Ss = 0.26(2.2576) = 0.5869 g ≈ 0.59 g

For the one-second spectral acceleration:

S1 / PGA = 0.5776(0.26) + 0.5967 = 0.1502 + 0.5967 = 0.7469

S1 = 0.26(0.7469) = 0.1942 g ≈ 0.19 g

Thus, the direct empirical conversion of the DSHA PGA gives Ss = 0.59 g and S1 = 0.19 g. These values provide an initial estimate; however, because they are based on generalized international regression data, they were not adopted directly as the final response-spectrum values. Instead, they were used as a published methodological check and were further compared with Pakistan-specific code-based spectral parameters.

Stage 2: Regional BCP-2021 Interpolation for Wah Cantt

The Building Code of Pakistan 2021 provides district-wise seismic hazard values including Ss, S1 and PGA at different hazard levels. However, Wah Cantt is not separately listed in the available district-wise table. Therefore, the nearest representative districts, Attock and Rawalpindi, were used to estimate the regional spectral parameters for Wah Cantt. This is reasonable because Wah Cantt lies geographically between Attock and Rawalpindi and belongs to the same northern Punjab/Potwar Plateau seismic environment.

Table 4. BCP-2021 regional seismic hazard values used for Wah Cantt interpolation.

District	Ss 2475 yrs (g)	S1 2475 yrs (g)	PGA 2475 yrs (g)	PGA 475 yrs (g)
Attock	1.3080	0.3756	0.5820	0.3133
Rawalpindi	1.2295	0.3708	0.5556	0.3168

Because Wah Cantt is located between these two districts, the interpolated regional value was estimated as the average of the adjacent district values:

X_Wah = (X_Attock + X_Rawalpindi) / 2

For short-period spectral acceleration:

Ss,BCP-Wah = (1.3080 + 1.2295) / 2 = 1.26875 g ≈ 1.27 g

For one-second spectral acceleration:

S1,BCP-Wah = (0.3756 + 0.3708) / 2 = 0.3732 g ≈ 0.373 g

For 475-year PGA:

PGA_475,BCP-Wah = (0.3133 + 0.3168) / 2 = 0.31505 g ≈ 0.315 g

Therefore, the interpolated BCP-2021 regional values for Wah Cantt are:

Ss, BCP-Wah = 1.27 g, S1, BCP-Wah = 0.373 g, PGA_475, BCP-Wah = 0.315 g

Stage 3: Normalization of BCP Spectral Shape to DSHA PGA

The DSHA result represents the site-specific deterministic demand obtained from the controlling source, whereas the BCP values represent regional probabilistic seismic hazard parameters. To combine both sources of information, the interpolated BCP spectral parameters were scaled to the DSHA PGA level. This preserves the Pakistan-specific regional spectral shape of BCP-2021 while making the final values consistent with the adopted deterministic PGA of the site.

The normalization factor was calculated as:

alpha = PGA_DSHA / PGA_475, BCP-Wah

alpha = 0.26 / 0.315 = 0.825

The factor alpha = 0.825 indicates that the DSHA PGA is approximately 82.5 percent of the interpolated BCP 475-year PGA for Wah Cantt. This factor was applied to the interpolated BCP spectral acceleration parameters.

For short-period spectral acceleration:

Ss, adopted = alpha(Ss, BCP-Wah) = 0.825(1.27) = 1.047 g ≈ 1.05 g

For one-second spectral acceleration:

S1, adopted = alpha(S1, BCP-Wah) = 0.825(0.373) = 0.308 g ≈ 0.31 g

Therefore, the final adopted spectral acceleration parameters for the POF Wah Cantt G+7 building are:

PGA_DSHA = 0.26 g, Ss = 1.05 g, S1 = 0.31 g

The final values were not obtained by directly equating the seismic coefficient to PGA. The procedure first converted PGA to spectral acceleration using the published Lubkowski and Aluisi (2012) equations, then compared the results with the BCP-2021 regional spectral values interpolated between Attock and Rawalpindi. The direct empirical equations gave Ss = 0.59 g and S1 = 0.19 g, whereas the BCP-calibrated method gave Ss = 1.05 g and S1 = 0.31 g. The BCP-calibrated values were adopted because they retain the Pakistan-specific regional spectral shape while remaining consistent with the site-specific DSHA PGA obtained for Wah Cantt.

Table 5. Summary of adopted PGA-to-spectral-parameter conversion.

Parameter	Value	Basis
Adopted DSHA PGA	0.26 g	Maximum deterministic PGA from controlling source, MBT
Direct empirical Ss	0.59 g	Lubkowski and Aluisi (2012) PGA-to-Ss equation
Direct empirical S1	0.19 g	Lubkowski and Aluisi (2012) PGA-to-S1 equation
Interpolated BCP Ss for Wah Cantt	1.27 g	Average of Attock and Rawalpindi
Interpolated BCP S1 for Wah Cantt	0.373 g	Average of Attock and Rawalpindi
Interpolated BCP PGA 475 yrs	0.315 g	Average of Attock and Rawalpindi
Normalization factor alpha	0.825	0.26 / 0.315
Final adopted Ss	1.05 g	BCP spectral shape scaled to DSHA PGA
Final adopted S1	0.31 g	BCP spectral shape scaled to DSHA PGA

The adopted response-spectrum parameters are therefore suitable as preliminary seismic input values for structural verification of the existing G+7 building.

6. Conclusions

- A site-specific DSHA was conducted for the newly constructed G+7 building at POF Wah Cantt by considering seismogenic faults within approximately 150 km of the site.
- The Main Boundary Thrust was identified as the controlling seismic source, producing the maximum tabulated PGA of 0.26 g from Boore and Atkinson (2008).
- The preliminary response-spectrum parameters adopted for structural verification are Ss = 1.05 g and S1 = 0.31 g, obtained by calibrating the DSHA PGA with published PGA-to-spectral conversion relationships and BCP-2021 regional spectral interpolation.
- As this study was carried out with limited resources, the results can be further refined by conducting in-depth study of the local geology and considering further faults.

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